Development and Test of a Millimetre-Wave ISAR Images ATR System

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Abstract:

The Defence R &D Canada -Valcartier is developing an efficient ATR algorithm capable of classifying millimetre-wave images using a back-propagation neural network. This neural network was developed and tested using the MATRIX 2005 ISAR data bank featuring the signatures of T-72, BMP-2, T-62 and the ZSU-23-4. The neural network was developed with MATLAB Toolbox Neural Network 3.0[2] and the results are compared with the HNet[3] ATR system. Specialized M files were developed to evaluate the performance of the neural network providing the confusion matrix and the ROC curves.

1- Introduction

The objective of this work is to develop and characterize an ATR system capable of classifying four vehicles based on their ISAR images. The images were extracted from recorded data provided by the NATO SET-069 task group. For many years Defence R&D Canada (DRDC) has been exploiting the capabilities of a commercial product HNET in its development effort on target classification. Many studies were conducted on this product and very good performances were obtained (1). In this paper, the author proposes a standard neural network for the classification of the four targets. The dimension of the ISAR images was restricted to a dimension of 32 x 32 pixels to obtain a classifier that requires acceptable processing power. The aim is to have an ATR algorithm that has good performance but that can also be implemented on a DSP or dedicated processor for real-time operation. The paper is divided in 5 parts: the ISAR image preparation, the classifier structure, the training and validation process, the results and a conclusion.

2- Preparation of the ISAR images

ISAR images were generated from NATO SET-069 data files using Fast Fourier Transform (FFT) with Hanning windowing. The images were then divided in two groups; the training files and the validation/test files. The range resolution of an ISAR image is determined from the radar bandwidth used during the measurement. The cross-range resolution depends on the number of radar sequences used in the cross-range FFT processing. It was determined that to achieve the same dimension in the cross-range axis, the number of radar sequences should be 200. For the proposed algorithm, the ISAR

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[2] MATLAB and the Image Processing Toolbox are trademark of The MathWorks
[3] HNet: Holographic Neural Network Copyright AND Corporation

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image should have the same resolution in both axes to minimize distortion during the image rotation process.

Figure 1 presents the procedure used to produce the stabilized ISAR image. The first step is a crop operation that extracts a 100 x 100 pixel image of the target from original image after it was logarithmic scaled. The image is then converted to an intensity scale using the '*mat2gray*' function of the MATLAB Image Processing Toolbox (2). This operation limits the values of the image pixels to a scale of 0 to 1. The rotation correction is then applied and followed by an image size reduction to a format of 32 x 32 pixels. Finally, the image is converted to a line vector and stored in a training or validation/test file.

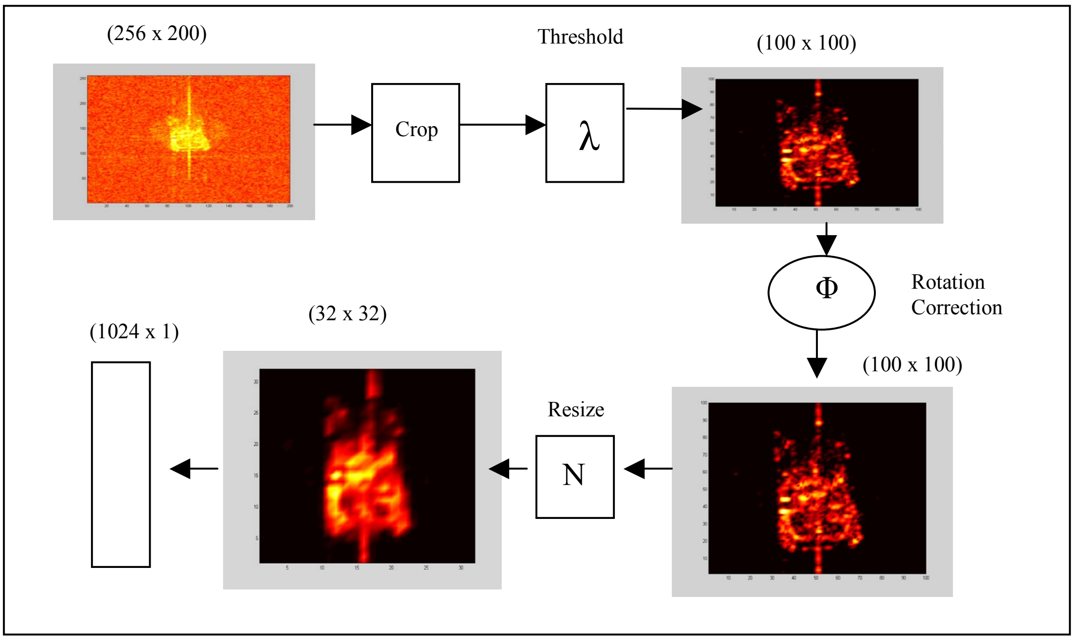

Figure 1 - ISAR image preparation steps

Figure 2 shows two generated ISAR images of the same vehicle at different rotation angles after being corrected by the process presented in Figure 1. The resulting images are all orientated to the vehicle position at the start of the data recording. This correction results in an apparent effect of the radar rotating around the target. This is very useful to visualize the stability of the scattering points of the vehicle as the position of the radar moves around it.

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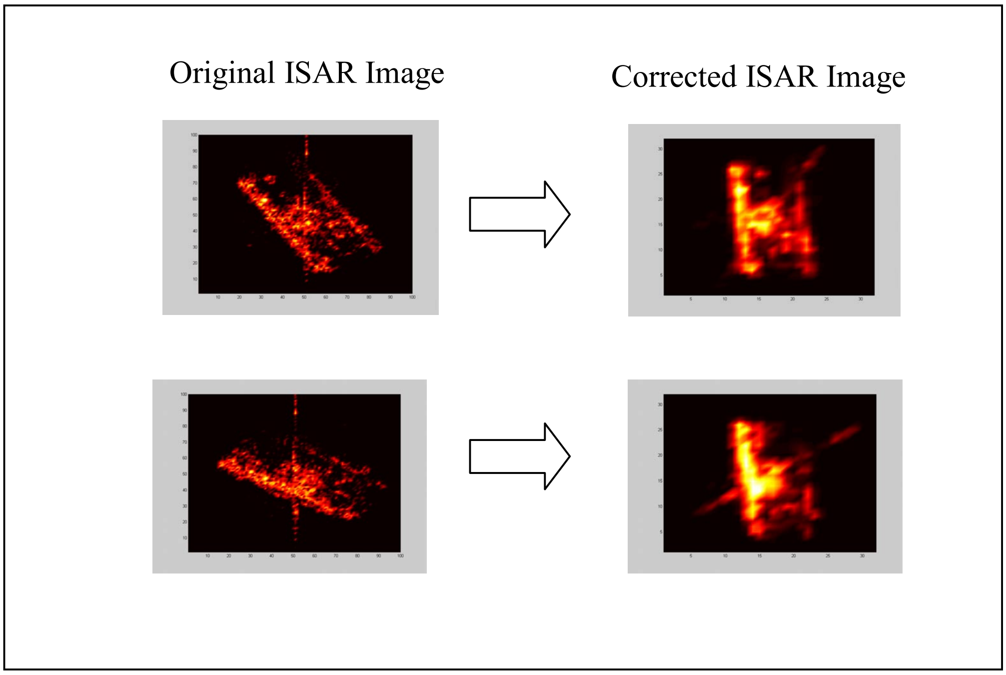

Figure 2 - Example of corrected Images

From a typical SET-069 group file, a total of 60 ISAR images were produced. Figure 3 presents a mosaic of the 60 images obtained from a typical BMP-2 file.

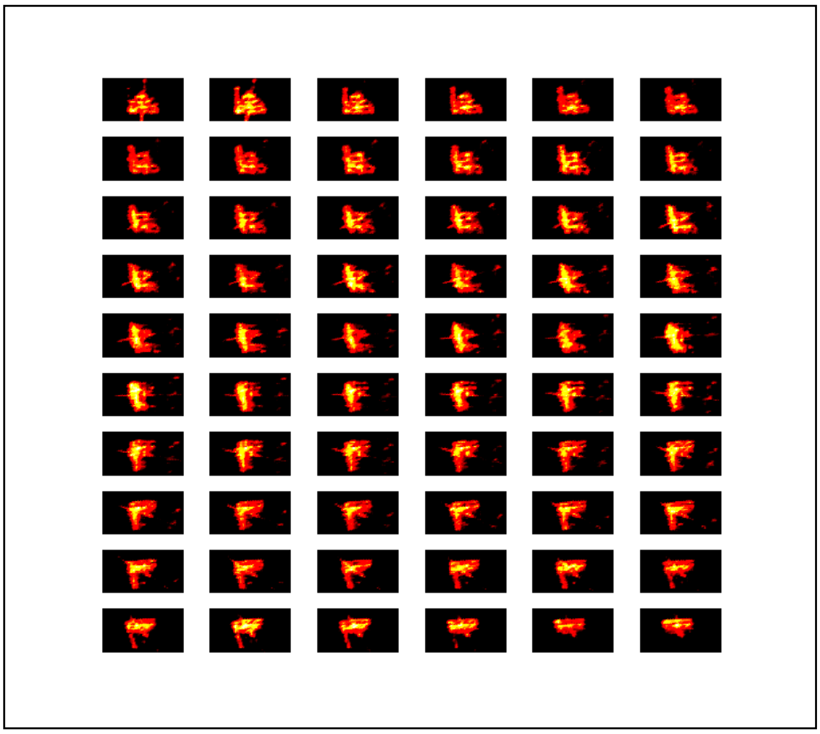

Figure 3 - Mosaic of ISAR images (BMP-2)

It is this set of images that was divided into two groups, one to train of the ATR classifier and the other to test /validate it.

3- The Classifier Structure

Figure 4 presents the basic structure used in the ISAR ATR system. The ATR system is composed of an assembly of single class classifiers (SCC). Each SCC is trained and optimized individually using a specific training file. The number of SCCs depends on the number of target classes and should normally be N+1 because one SCC is reserved for clutter and other non-target images. In the design of the ISAR ATR system studied here, the number of SSCs was set to 4 because the SET-069 data bank provides signatures of only 4 types of vehicles and not clutter. As the goal of this assessment was to compare the performance of the back-propagation classifier to the HNet classifier the use of clutter images was not considered essential.

As presented in Figure 4, the output of each SSC is fed to a 'greatest of'' (GO) detector stage that provides the result of the classification process by selecting the highest score of all the outputs. Other ways of combining the outputs of the SCC were studied but the one selected seems to provide the best performance.

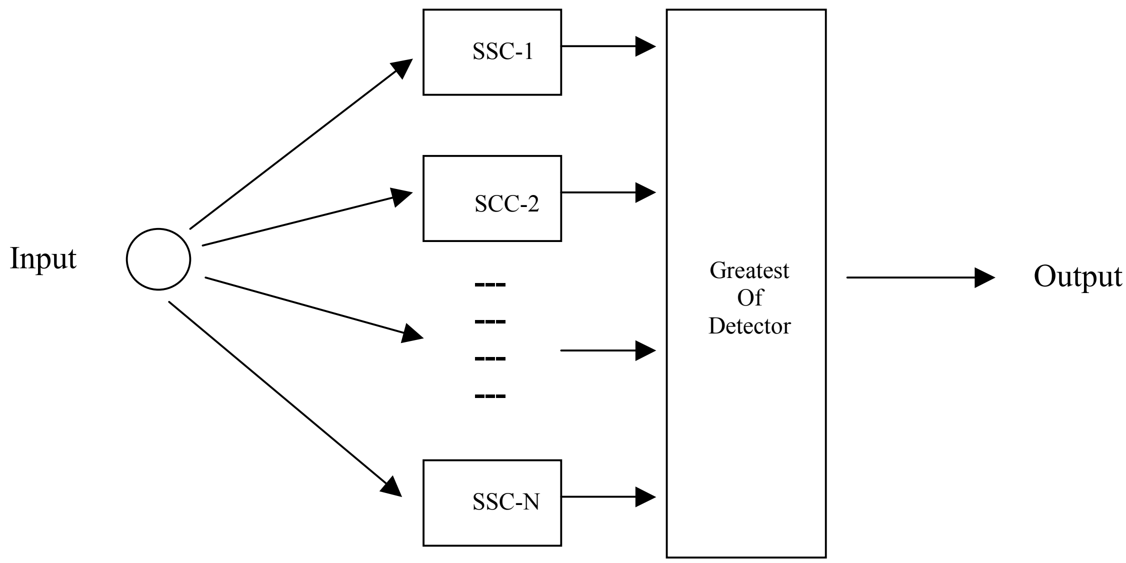

Figure 4 - Structure of ISAR ATR system

Each SCC are defined using the 'NEWFF' matlab[4] function as presented in (1). The training is performed using the TRAIN function as presented in (2).

```
net1 = newff([min_t;max_t].',[1,1],{'tansig','tansig'},'traingdx'); (1)
net1 = train(net1{i1},t(:,1:1024).',response);                      (2)
```

The neural network within a SCC consists of two stages each one having a 'tansig'(2) non-linear transfer function. The number of outputs of the second stage is 1, and the output value can take any value between –1 and +1. The training conditions were defined by default when the NEWFF function was called but some could be optimized prior to the training phase. The training process was performed using the 'TRAINGDX' training process which has a variable learning rate algorithm. The learning rate was optimized during the learning process to provide fast convergence.

[4] MATLAB is a trademark of The Mtaworks

Figure 5 presents the layout of the SSC. In this figure, there is also a illustration of the way the input ISAR image is converted to a input line vector. The input vector of has a dimension of 1024 pixels. The parameters W_i are the weighting coefficients and the b_i parameters are the bias parameters used in the back-propagation neural network.

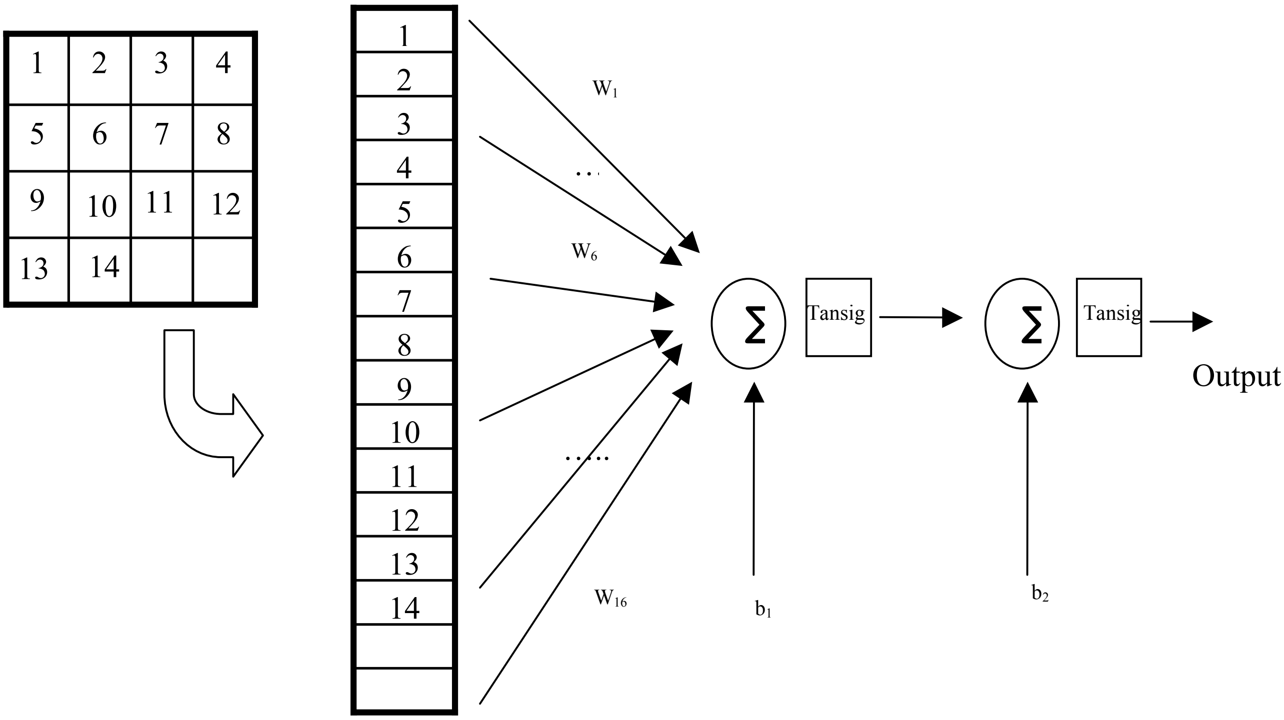

Figure 5 - Layout of the back-propagation neural network

4- The training and validation process

Each SCC of the ISAR ATR classifier was trained until it could identify with low probability of error, ISAR images of its class. The specific training file for each class contained ISAR images of the class vehicle as well as counter-class images from other classes, in order to distinguish between the vehicles. Table 1 presents the list of ISAR image files used for training and the validation files. In each of the training files, there are 30 images from each of the target classes. The training file has a dimension of 120 (4 x 30) images with a specific response vector for each class. The validation files were made of other images not presented to the SCC during the training phase. However, for the ZSU and BMP-2 classes, the number of ISAR files is very limited and the validation file was only populated by images provided by the same ISAR file as the training file. In the case of the T72 and T62 targets, a greater number of ISAR images were used to populate the validation file.

Table 1
List of ISAR data files for each class

		Training		Validation	
	ISAR File name	Percentage	# of images	Percentage	# of images
ZSU					
	t51bb	50 %	30	50 %	30
T72					
	t47gc	50%	30	50 %	30
	t47dv	0 %	0	100%	60
	t47db	0 %	0	100%	60
	t47ct	0 %	0	100%	60
	t47cb	0 %	0	100%	60
	t47cn	0 %	0	100%	60
	t47ba	0 %	0	100%	60
	t47au	0 %	0	100%	60
	t47an	0 %	0	100%	60
T62					
	t55ah	50 %	30	50 %	30
	t55ai	0 %	0	100%	60
	t55ap	0 %	0	100%	60
	t55aj	0 %	0	100%	60
BMP-2					
	t43bh	50 %	30	50 %	30

The training files were populated with the same number of ISAR images for the four classes. The T72 class can serve as example to describe the way each training file was made. The training file of this class was composed of 30 images from the file ‘T51bb’, 30 images from the file ‘T47gc’, 30 image from the file ‘T55ah’ and 30 images from the file ‘T43hh’, for a total number of images of 120. As described in a previous section, the images were resized to form 1024 element vectors. An extra element was added to each of the vectors to include the class information. For the example, all the images from a file other than those of the T72 are marked –1, while images from file ‘T47gc’ are marked +1. This 1025th element is used in the training phase as the requested response of the SCC. All training files were prepared in the same manner.

Figure 6 presents the specific response vector for each class. The four training files are constituted of the same ISAR images but only the response vector is different.

During the training phase of each SCC, the training file was presented to the SCC until the output response of the SCC corresponds to the required output within a specific error. To optimize the convergence effect, the images were selected randomly within the file from one epoch to the other.

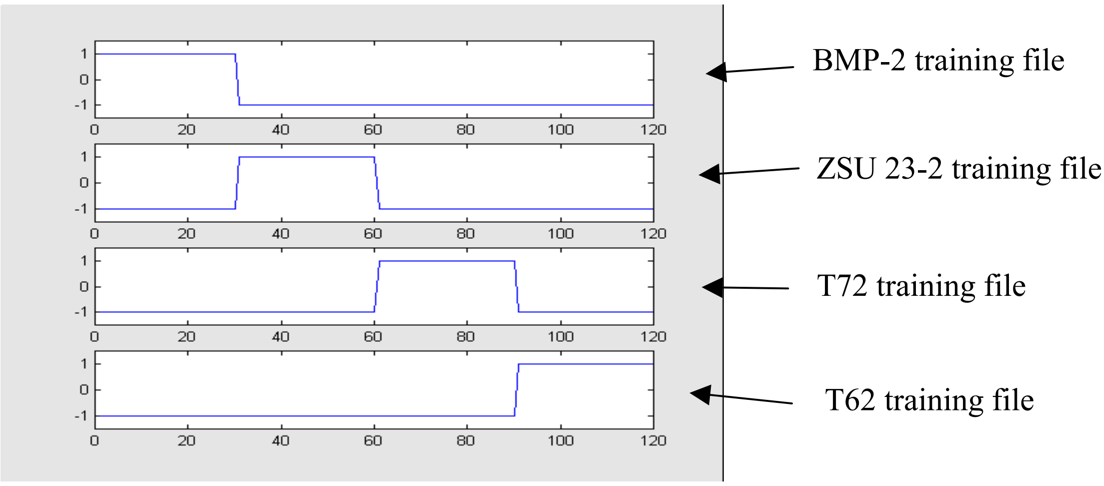

Figure 6 - Response vector for each training file

5- Results

During the training phase, the four training files were applied to the four SCCs with the Matlab "TRAIN" function. The function provides the mean square error of the classifier output as a function of the epoch. With this, operator can then observe the progression of the training as presented in Figure 7 where the error reached a very low value after 300 epochs. After 300 epochs, the training was stopped and the SCC was ready for evaluation with the validation data.

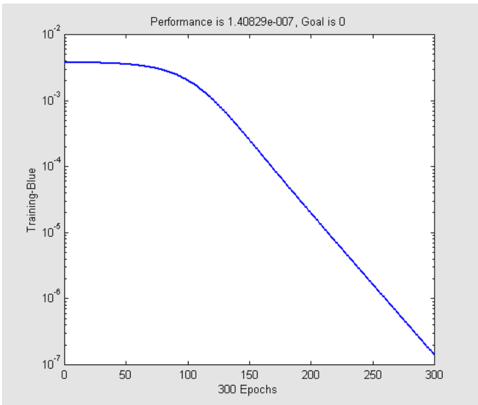

Figure 7 - Output error obtained during training process (Back Propagation Neural Network)

The response of each SCC when presented with a validation ISAR image is an output value between –1 and +1. Function 3, as indicated below, is the MATLAB call that produces the SCC response to the stimulus input. The SCC parameters are included in the *'net1'* parameter. The validation data are located in the *'val1'* parameter. The output results are placed in the '*r_val'* parameter. Figure 8 shows the output produced by the T72 SCC when the T72 ISAR image validation data were presented to it. Most of the output values are at +1, indicating that the SCC was able to classify most of the ISAR images as T72, which is correct classification.

```
r_val = sim(net1,val1(:,1:1024).');                (3)
```

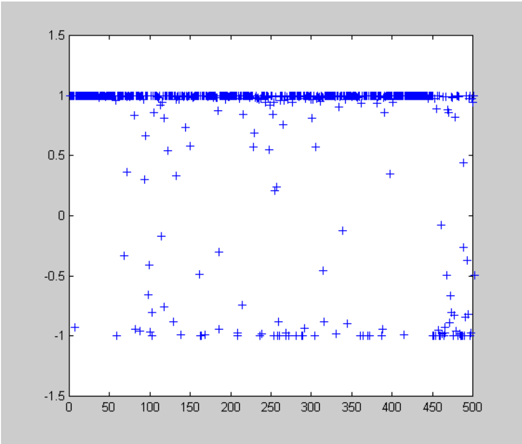

Figure 8 - Output of the T72 classifier for the T72 validation file

Figure 9 shows the output of the T72 SCC when presented with the T62 validation file. As expected, the output of the SCC is most of the time –1 indicating that the SCC is able to reject these counter-class images.

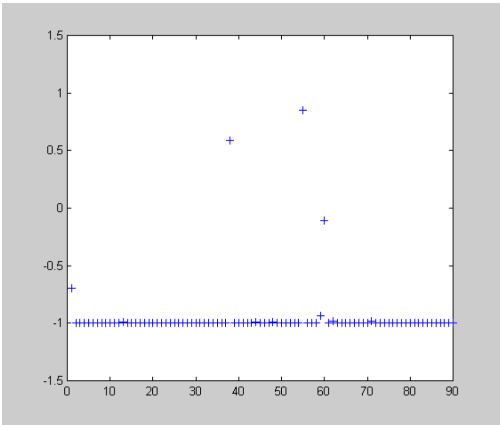

Figure 9 - Output of the T72 classifier for the T62 validation file

To summarize the performance of the four SCCs, the confusion matrix was computed for the case of the training files being presented to the SCC and also for the more interesting case of the validation files being presented. The confusion matrix was computed using the classifier structure presented in Figure 4. Each image vector was simultaneously presented to the four SCCs and the outputs of the SCCs were compared in the GO detector to provide a single output for the ATR classifier. The confusion matrix values were compiled from the outputs for all input images. Table 2 presents the confusion matrix of the four SCCs when the training files were used. The values in the matrix diagonal are all 100% representing the perfect case where the classifier is able to correctly identify and reject all images

Table 3 presents the case when the validation data was presented to the ATR system. The values on the matrix diagonal are lower indicating more difficulty for each SCC to correctly classify the vehicle ISAR images.

Table 2 Confusion matrix - Training data -

	BMP-2	*T72*	*T62*	*ZSU*
BMP-2	**100%**	0	0	0
T72	0	**100%**	0	0
T62	0	0	**100%**	0
ZSU	0	0	0	**100%**

Table 3 Confusion matrix - Validation data -

	BMP-2	*T72*	*T62*	*ZSU*
BMP-2	**100%**	0.00%	0.00%	0.00%
T72	3.7%	**92.22%**	3.33%	4.07%
T62	10.67%	4.67%	**81.33%**	3.33%
ZSU	0.00%	0.00%	0.00%	**100%**

Table 4 presents the confusion matrix obtained from the HNet classifier with four SCCs that was trained and tested with the same files described in Table 1. The performance of the HNet classifier is a bit better than the back-propagation SCC but the difference is only for the T72 class. For the other cases, the two classifiers performed the same.

Table 4 Confusion matrix - Validation data –
HNet Classifier

	BMP-2	*T72*	*T62*	*ZSU*
BMP-2	**100%**	0.00%	0.00%	0.00%
T72	0.00%	**96.30%**	3.70%	0.00%
T62	8.00%	5.33%	**81.33%**	5.33%
ZSU	0.00%	0.00%	0.00%	**100%**

Another technique frequently used to evaluate the performance of an ATR system is to compute the Receiver Operating Characteristic (ROC) curves for each SCC(1). ROC curves are parametric plots showing the trade-off between correctly classifying images of target class and misclassifying counter-class images. The ROC curve is computed using the algorithm described in (3). The ROC curve of the back-propagation T72 and T62 SCCs are presented in Figure 10.

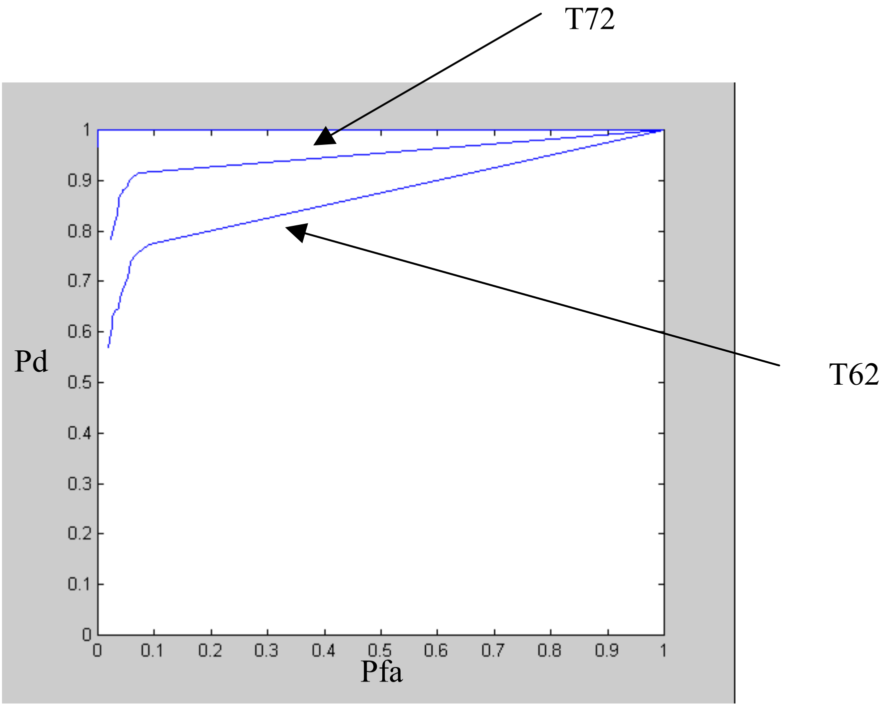

Figure 10 - ROC curves for the Back-Propagation SCCs

6 Conclusion

This study presented the development and the training process of a back-propagation neural network ATR system that performed almost as well as the HNet ATR system. The preparation of the data prior to the training phase was important to reduce the effect of the background and other artefacts. The performance of the back-propagation ATR system did not seem to be degraded by training to very low error values.

Bibliography

1 R.A English, Classifier Evaluation Methodology using the MSTAR Public data set, Defence R&D Canada – Ottawa, Feb 2003.
2 The MathWorks, Inc (1993), Image Processing Toolbox
3 The MathWorks, Inc (1998) Neural Network Toolbox

Development and Test of a millimetre-wave ISAR images ATR System

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DRDC - Valcartier

Matrix 2005

Outline

- ISAR images preparation
- The Classifier Structure
- The Training and Validation Process
- Results
- Conclusion

ISAR images preparation

The objective:

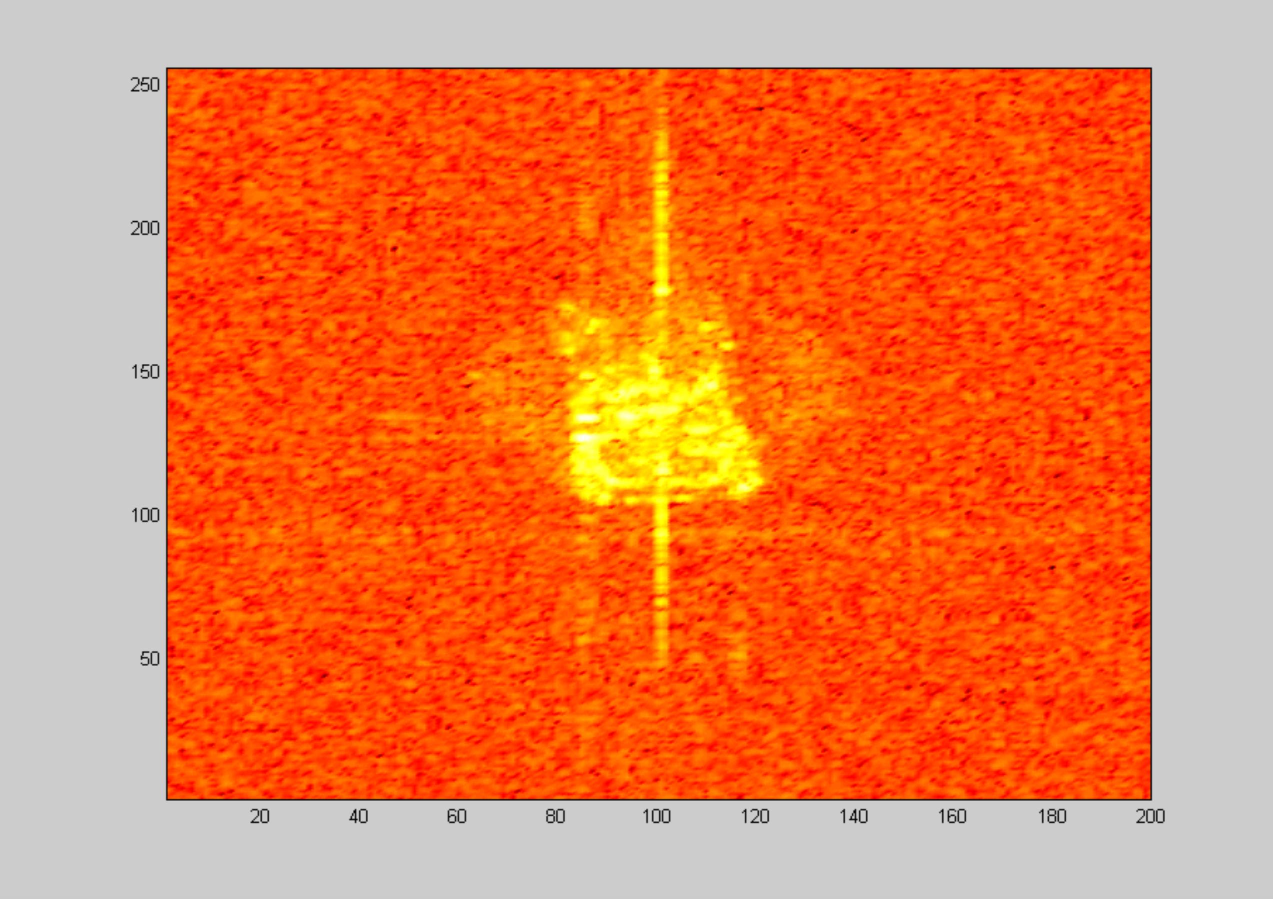
- Reduce the image scale to 32 x 32 pixel
- Eliminate the clutter/artefact
- Provide a constant aspect of the vehicle

Uncorrected ISAR Image BMP-2

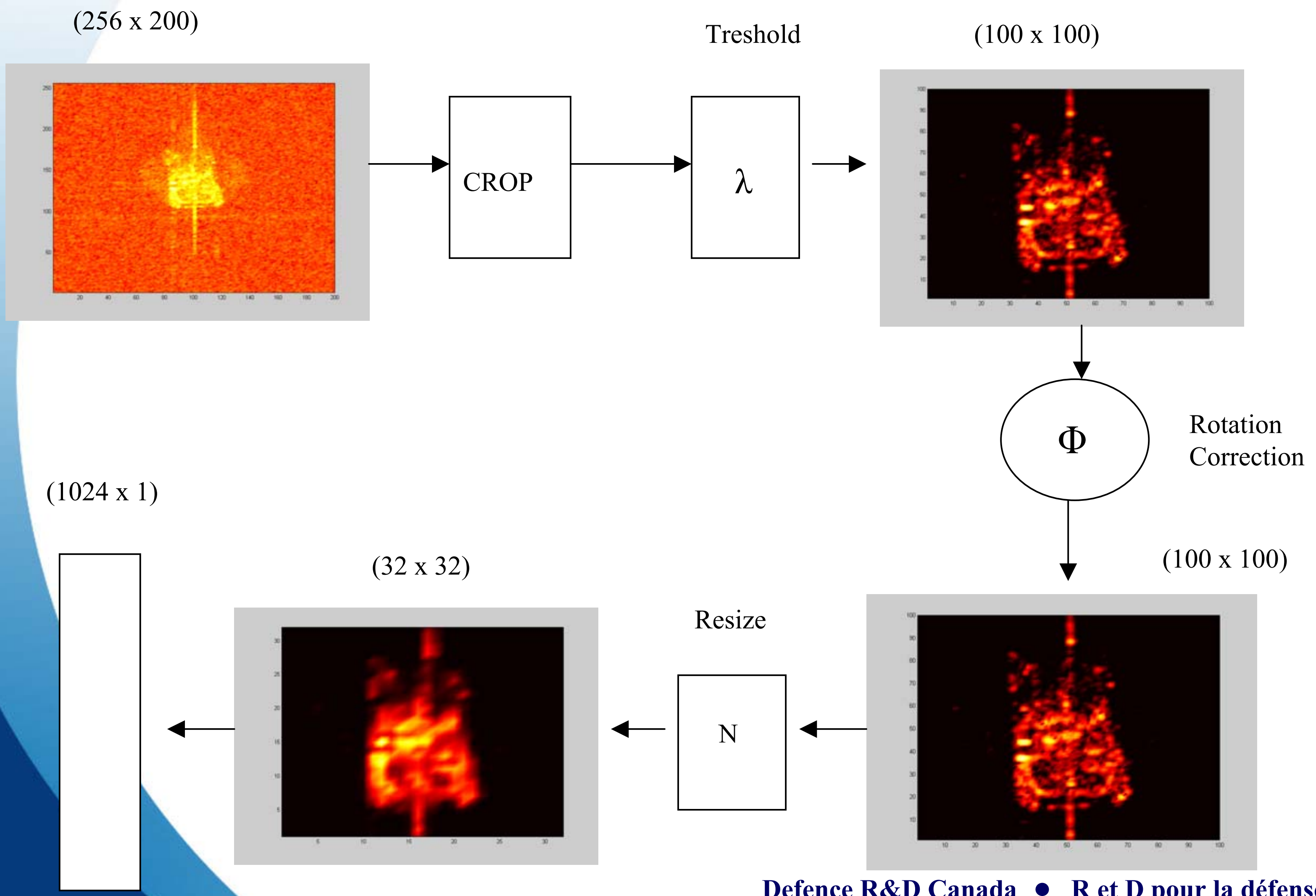
Phase 1

tgt43bh.rsg

First Image
Log Scale

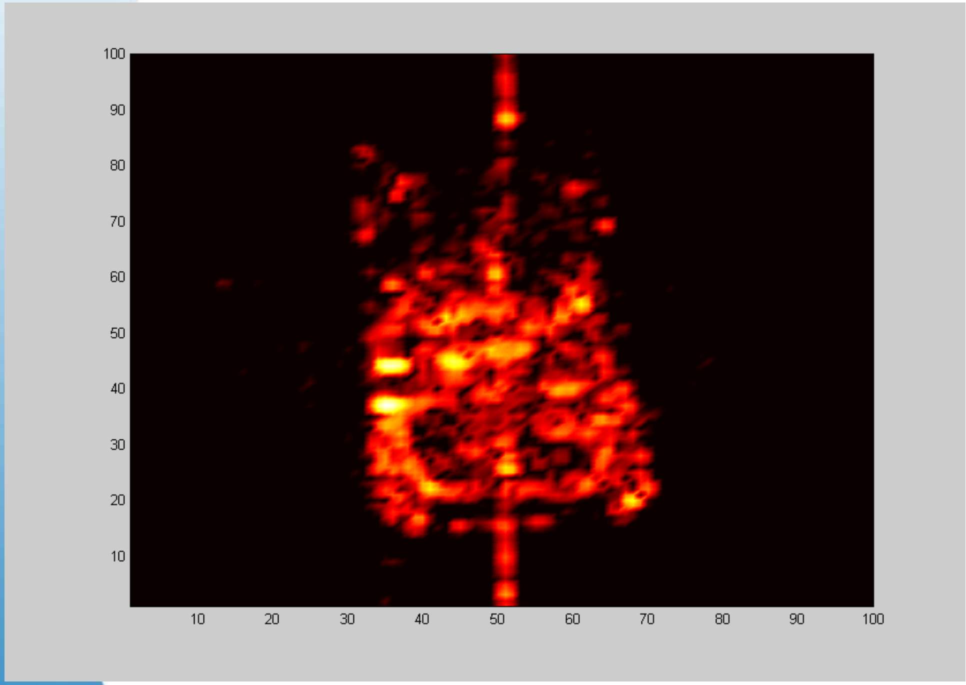


ISAR Image Preparation Steps

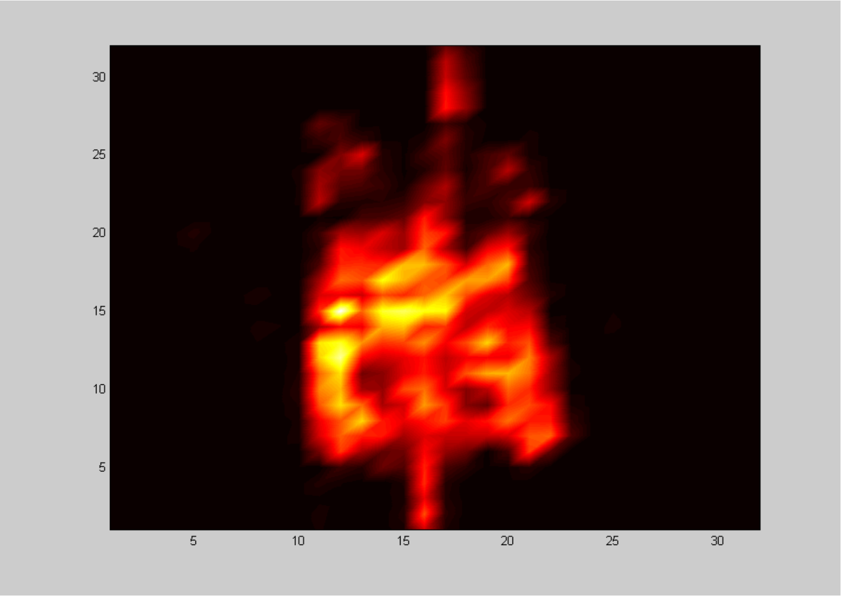


Example of The Correction Process (1)

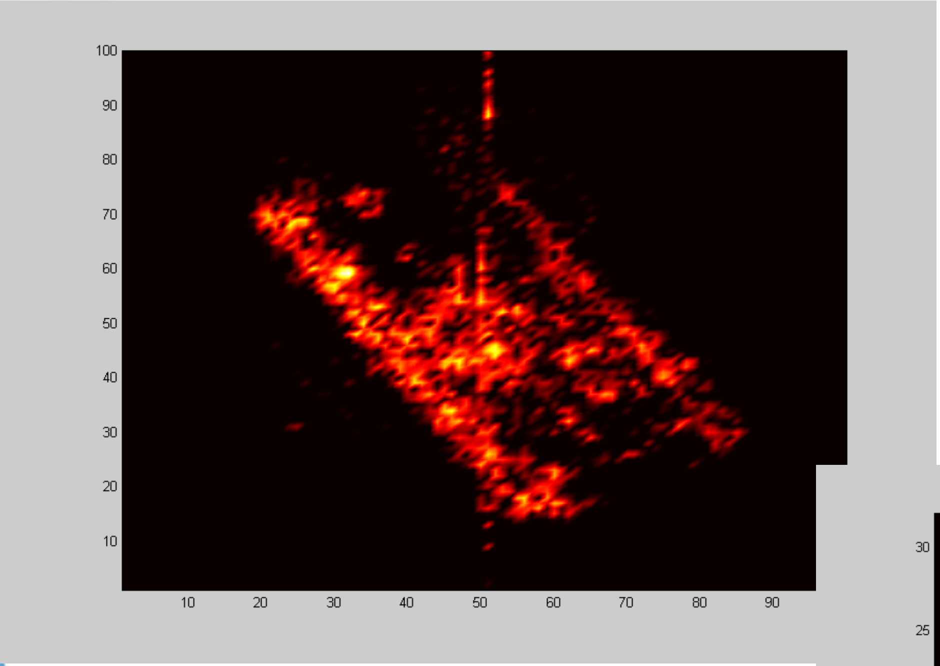
Threshold ISAR Image

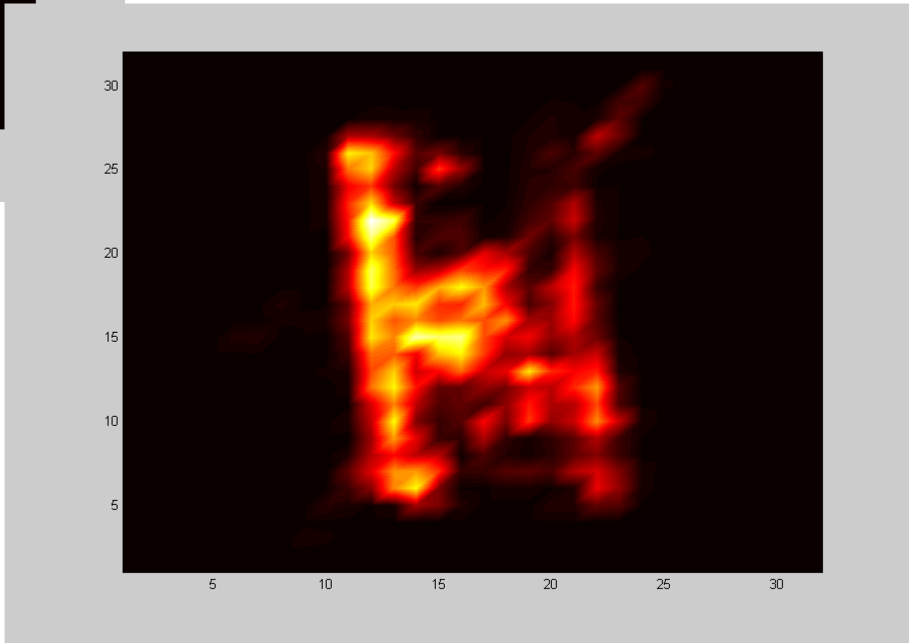


Output Resize Image (32 x 32)

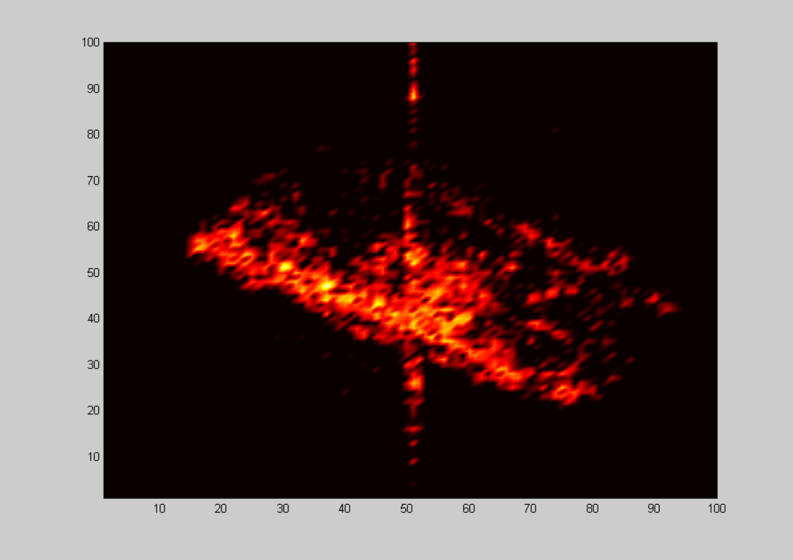


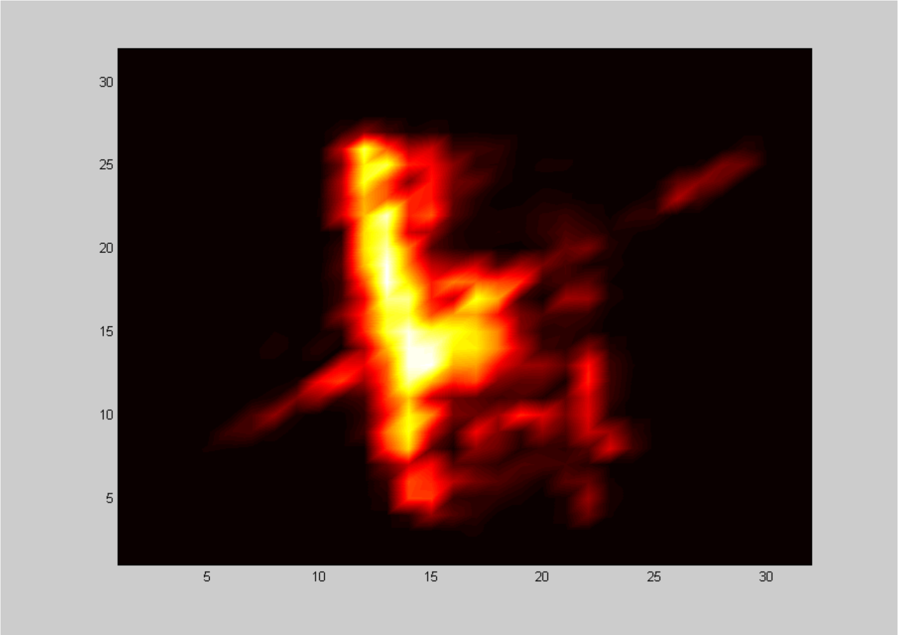
Example of The Correction Process (2)



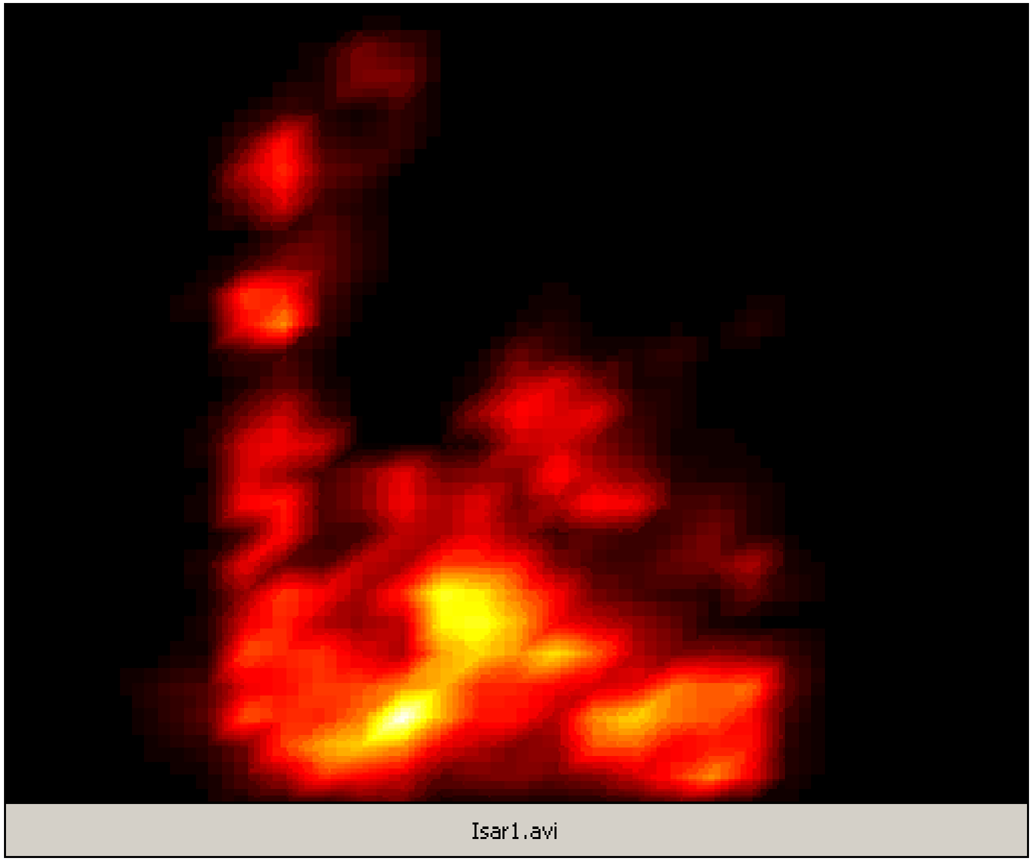


Example of The Correction Process (3)

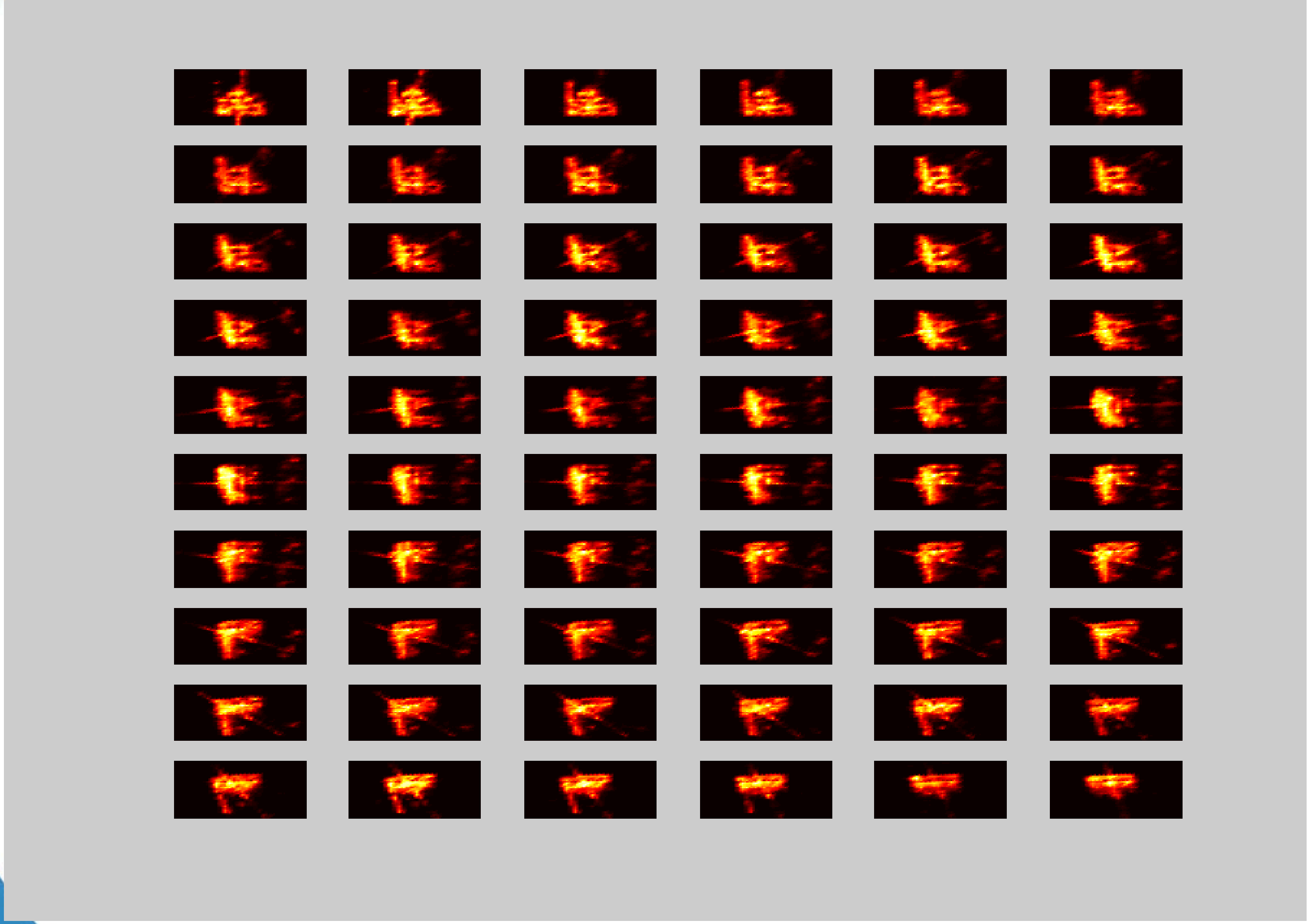




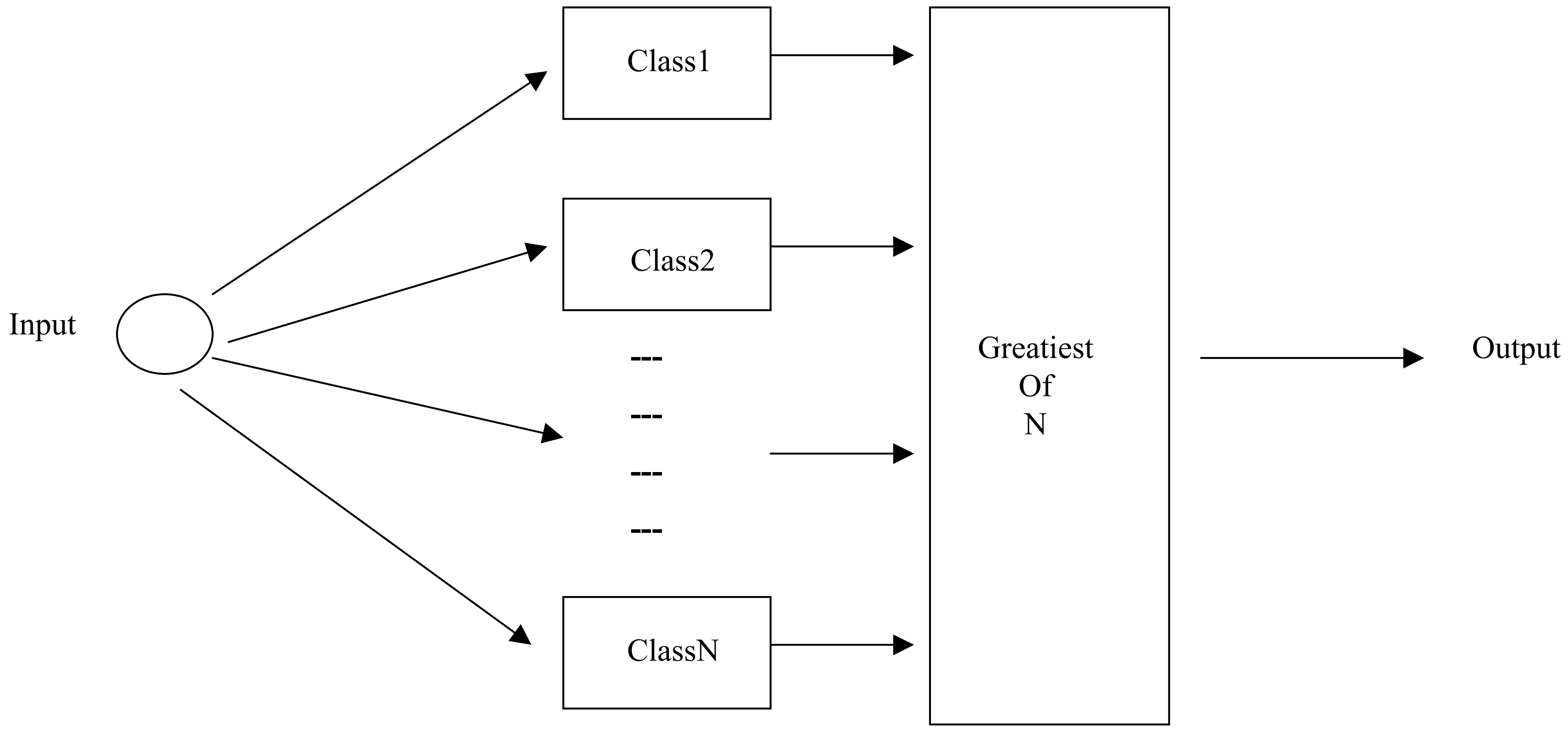
Movie of T72 Corrected images



ISAR Images BMP-2



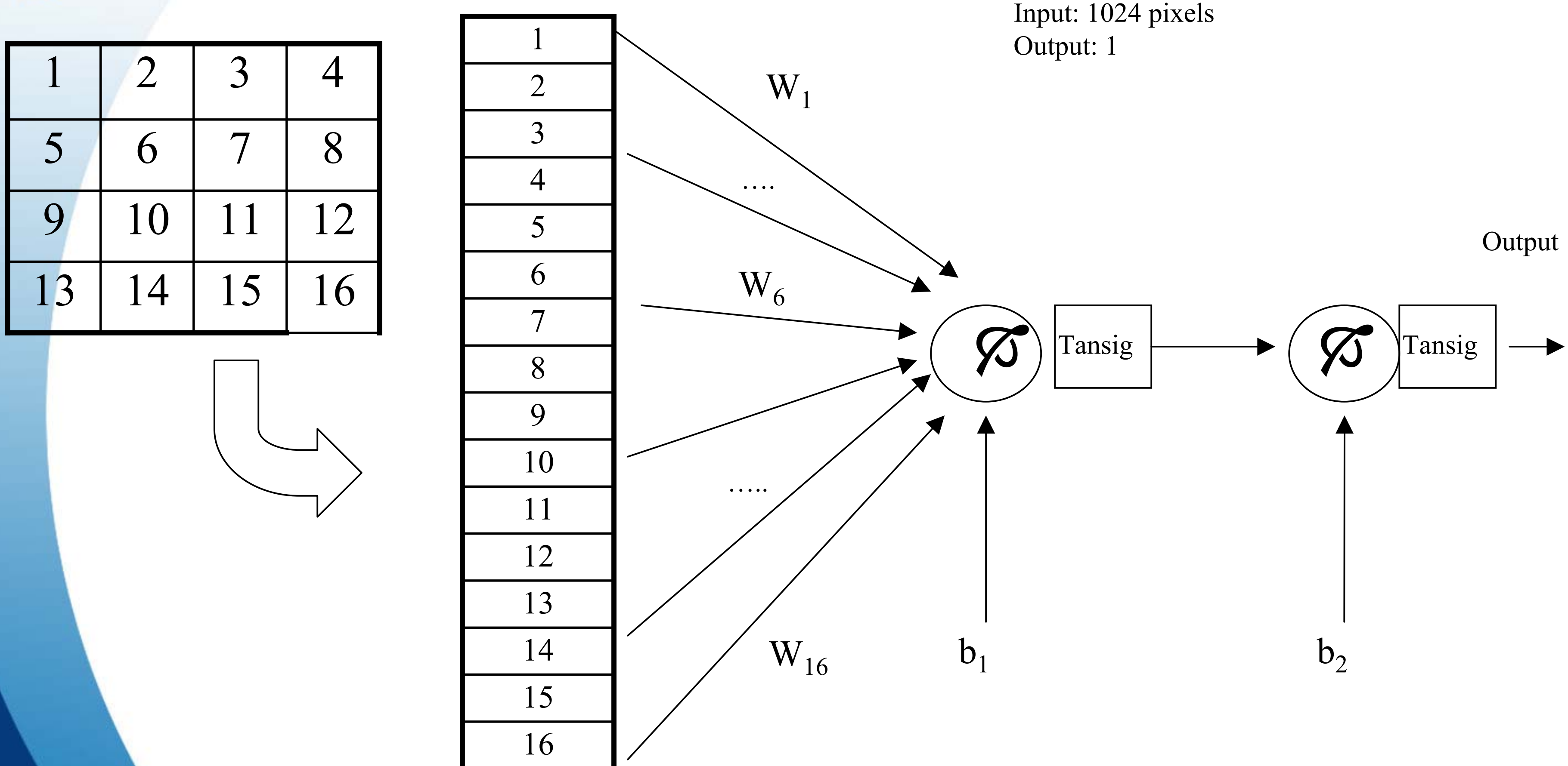
The ATR System Structure



The same input is presented to the N classifiers
Each classifier provide a linear output between -1 and +1

Structure of the Classifier

Type : Back-Propagation
Input: 1024 pixels
Output: 1



Wi : Weighting parameter
bi: Bias parameter

The training and Validation Process

Determine the way the training and the validation files are build

- First, a list of available data files is made
- A data quality check is done of every data file
- Data file are grouped in vehicle class
- Some data files are reserved for the training phase
- Rest of data files are used for validation tests

List of available data files

	Data file name	Training Percentage	Training # of images	Validation Percentage	Validation # of images
ZSU					
	t51bb	50 %	30	50 %	30
T72					
	t47gc	50%	30	50 %	30
	t47dv	0 %	-	100%	60
	t47db	0 %	-	100%	60
	t47ct	0 %	-	100%	60
	t47cb	0 %	-	100%	60
	t47cn	0 %	-	100%	60
	t47ba	0 %	-	100%	60
	t47au	0 %	-	100%	60
	t47an	0 %	-	100%	60
T62					
	t55ah	50 %	30	50 %	30
	t55ai	0 %	-	100%	60
	t55ap	0 %	-	100%	60
	t55aj	0 %	-	100%	60
BMP-2					
	t43bh	50 %	30	50 %	30

Description of the training file

- Is composed of data from the 4 classes.

- The dimension of the training file is the same for the each class
  (1024 +1) x 120

- One extra line is added to the data for class designation : +1 - class
  -1 : counter-class

Description of the validation file

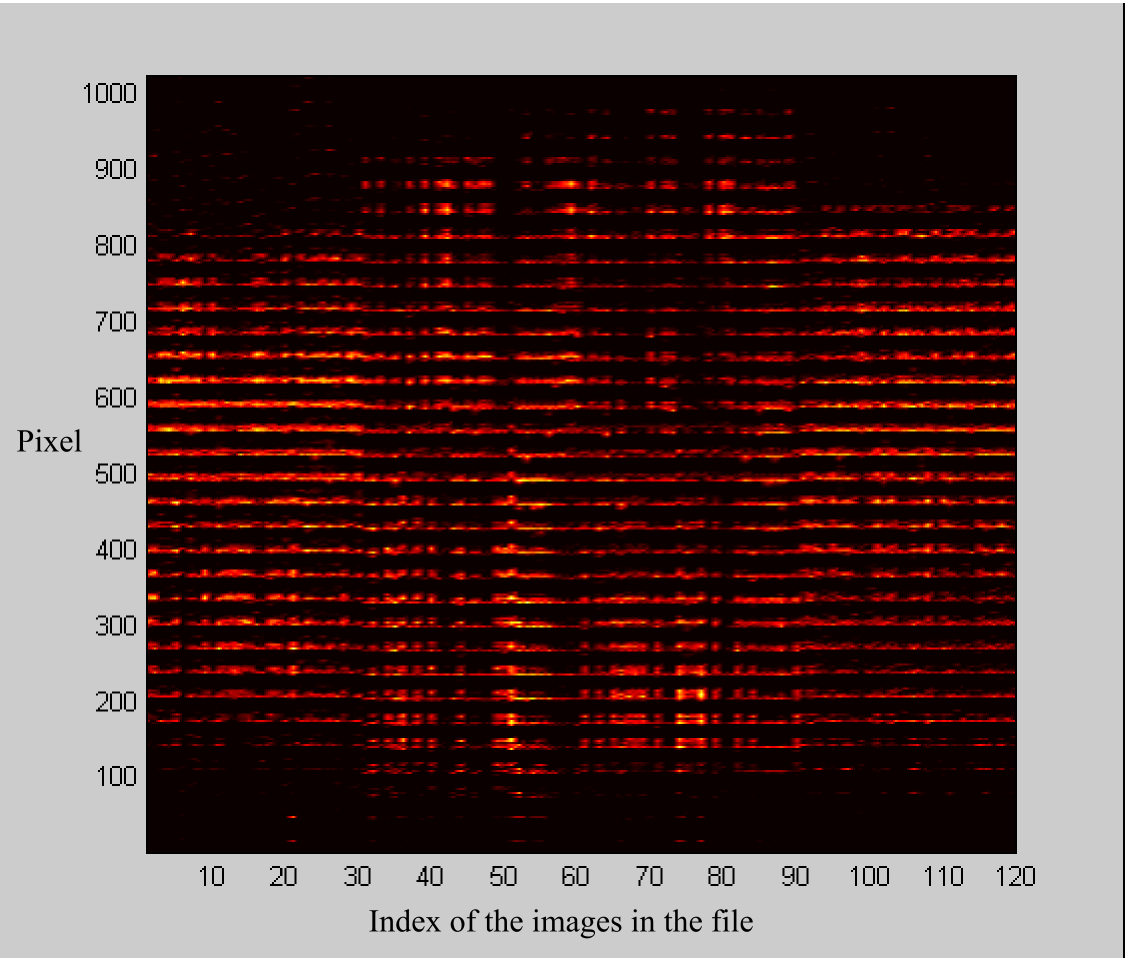
- Each class as its own validation file

- The dimension of the validation file depends on the amount of data available for the class
  (1024 +1) x N

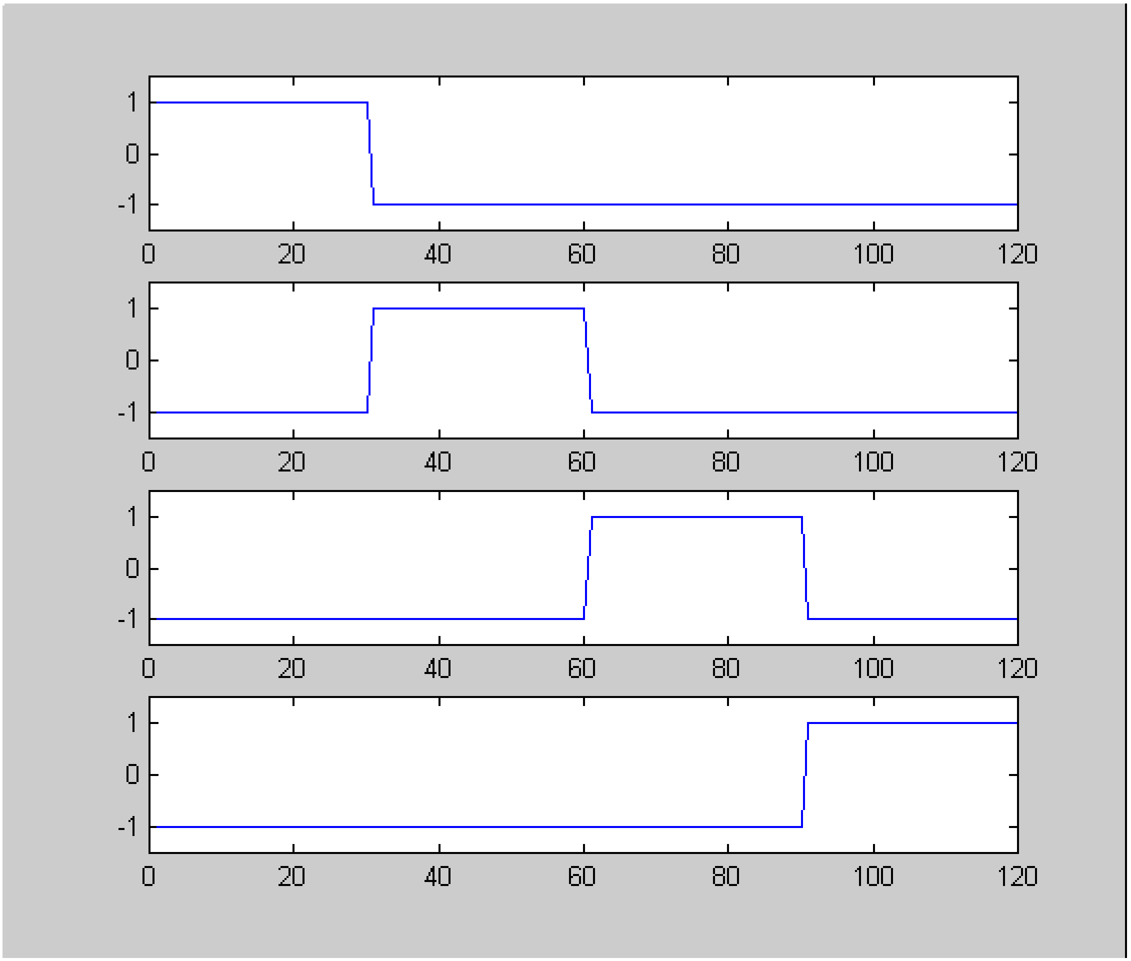
- One extra line is added; the value in this line is +1

Intensity plot of the data in a training file

Each column represents an ISAR image



Class Designation lines



BMP-2

ZSU 23-2

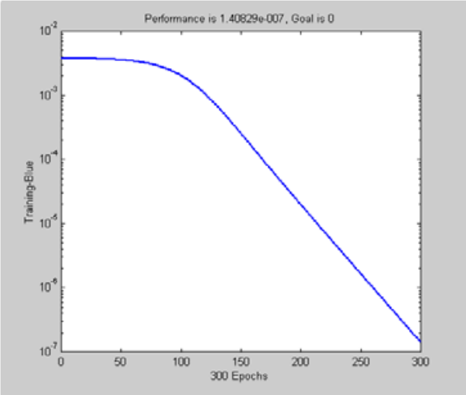
T72

T62

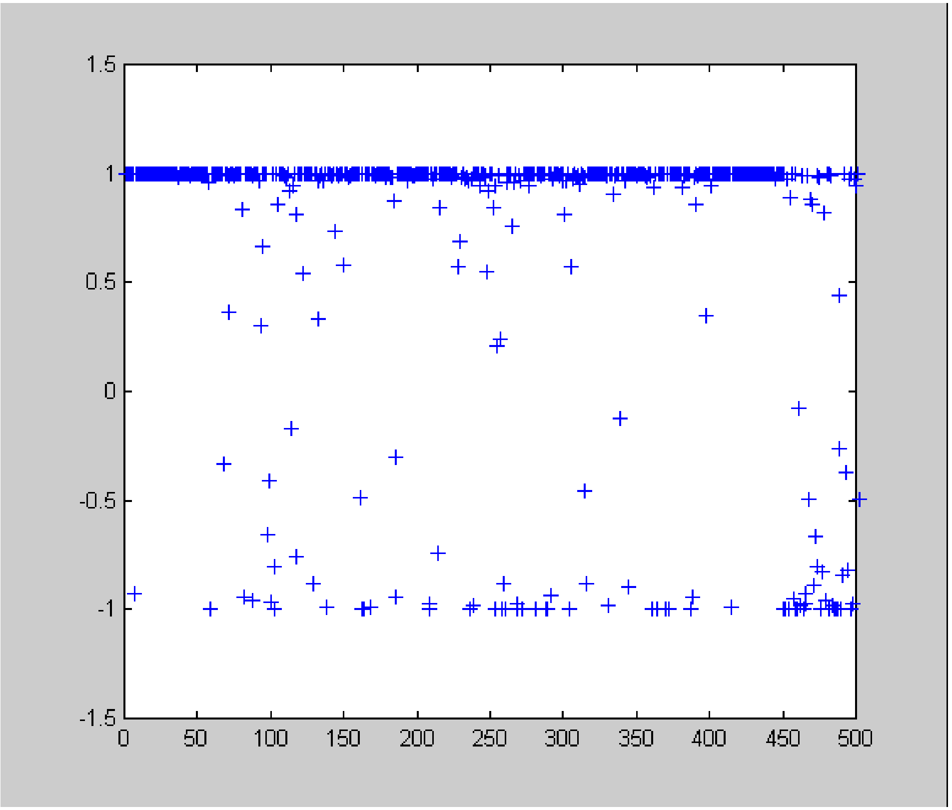
Index of the images in the file

Training and validation test

Output Error curve obtained during Training



Result of the T72 classifier - Validation file -



Confusion Matrix - BackPropagation Classifier -

Training

	BMP-2	T72	T62	ZSU
BMP-2	1.0	0	0	0
T72	0	1.0	0	0
T62	0	0	1.0	0
ZSU	0	0	0	1.0

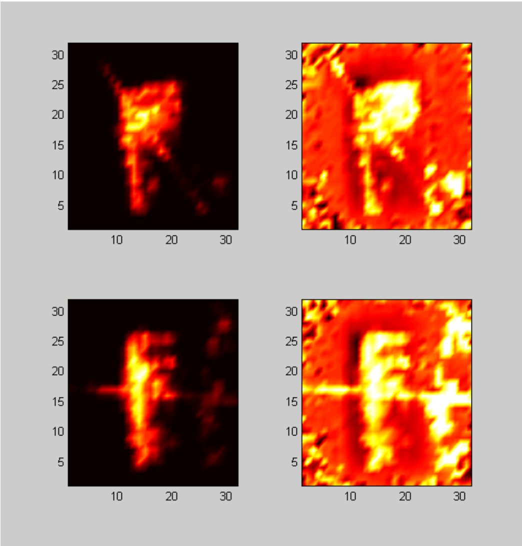
Validation

	BMP-2	T72	T62	ZSU
BMP-2	**100%**	0.00%	0.00%	0.00%
T72	3.7%	**92.22%**	3.33%	4.07%
T62	10.67%	4.67%	**81.33%**	3.33%
ZSU	0.00%	0.00%	0.00%	**100%**

Confusion Matrix - HNET Classifier

	BMP-2	T72	T62	ZSU
BMP-2	**100.00%**	0.00%	0.00%	0.00%
T72	0.00%	**96.30%**	3.70%	0.00%
T62	8.00%	5.33%	**81.33%**	5.34%
ZSU	0.00%	0.00%	0.00%	**100.00%**

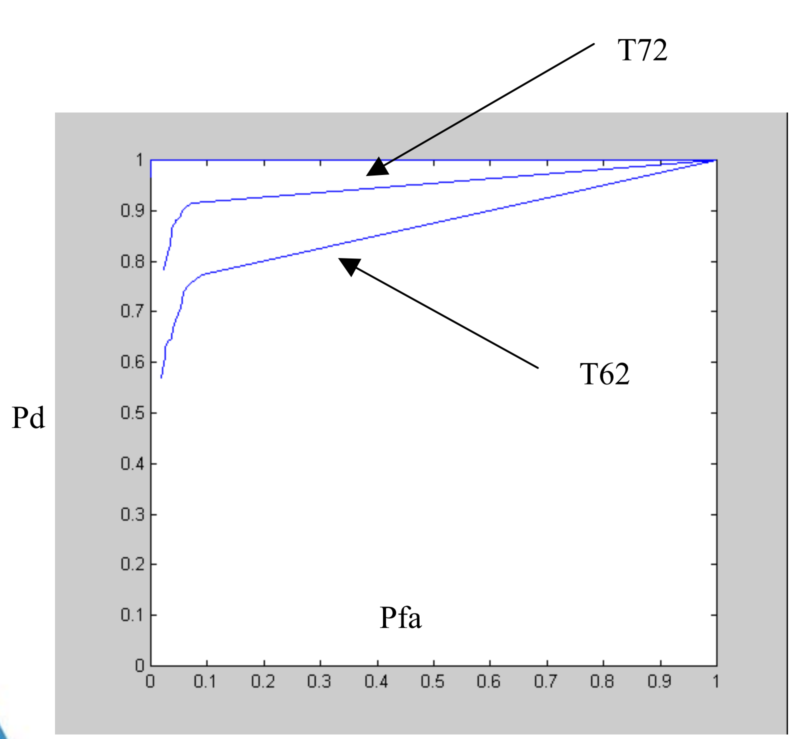
Original ISAR Image

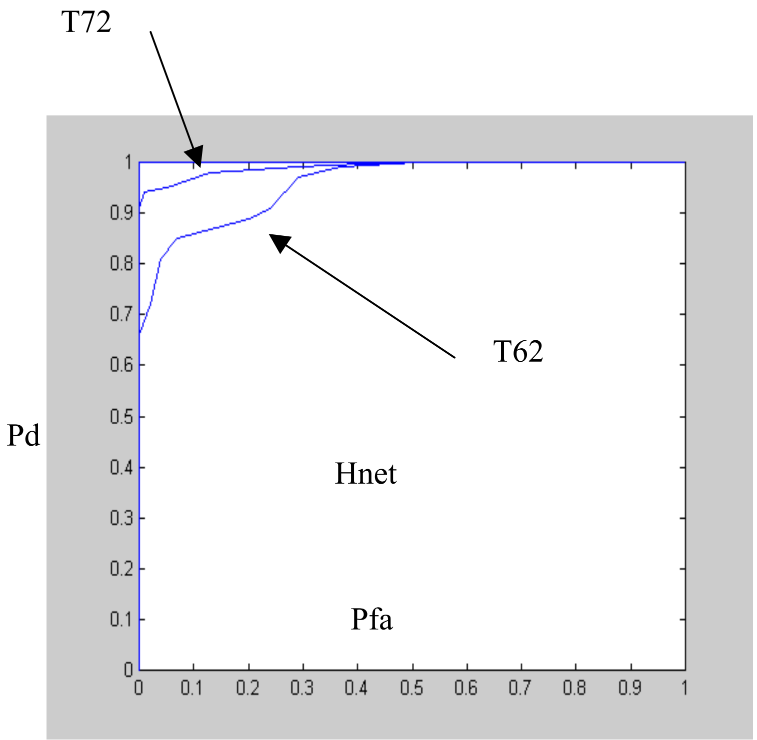


HNET Converted ISAR Image

The Receiver Operating Characteristic (ROC) Curves

- Computed for each classifier





Conclusion

- Demonstrated Back-Propagation can be used for ISAR image classification

- Perform as good as HNET classifier

- Can be implement on DSP for real-time application

- Need to be tested on more extensive image data bank

Question ?